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During February 1974, an airborne downlooking LIDAR system was flown in support of the Regional Air Pollution Study being conducted by the U.S. Environmental Protection Agency (EPA) in St. Louis, Missouri. The LIDAR system was used primarily to measure mixing layer height over the metropolitan area during the morning and evening transition periods. The flight plan consisted of south to north and west to east traverses with horizontal data resolution of 1.5 kilometers and a vertical resolution of 30 meters. (One traverse over the greater St. Louis area could be flown in about 10 minutes.) Final data are presented in computer-generated, iso-scattering curves plotted for altitude versus ground-distance along the particular traverse.

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## INTRODUCTION

Current techniques for measuring mixing layer height involve both direct and remote sensing techniques.[1] Direct measurements are typically made by radiosondes, a technique which is rather expensive per temperature profile obtained and, therefore, not generally used in situations requiring high spatial or temporal resolution. The principal advantage of the technique is that radiosondes provide a direct reading of the temperature, independent of humidity or particle loading. Direct measurements are also made with temperature sensors mounted on various aircraft. Remote monitoring techniques include acoustical sounders which provide high temporal resolution, but are seldom used in other than fixed locations. Acoustical techniques, however, are dependent on humidity as well as temperature, and are subject to false traces due to extraneous noise sources and, thus, at least at present, skillful interpretation of the results is necessary.

Light Detection and Ranging (LIDAR) devices have been used for measuring mixing height from fixed and mobile platforms.[2] These devices depend on scattering from aerosols trapped within the boundary layer. This method of measuring the mixing height requires that the tracer aerosol scatter the signal at the inversion interface. Other limitations include the high capital cost of the device and a need for skillful interpretation of the data. At the present time, however, the airborne LIDAR appears to be the only feasible method of measuring the height of the boundary layer over large geographical areas in relatively short time periods.

During February 1974, an airborne downlooking LIDAR system was flown in support of the Regional Air Pollution Study being conducted by the U. S. Environmental Protection Agency (EPA) in St. Louis, Missouri. The LIDAR system was used primarily to measure mixing layer height over the metropolitan area during the morning and evening transition periods. The flight plan consisted of south to north and west to east traverses with horizontal data resolution of 1.5 kilometers and a vertical resolution of 30 meters. (One traverse over the greater St. Louis area could be flown in about 10 minutes.) Final data are presented in computer-generated, iso-scattering curves plotted in altitude versus ground-distance along the particular traverse.

## OBJECTIVES AND APPROACH

The purpose for participation in the St. Louis studies was twofold. First, it was desirable to obtain data on the height of the boundary layer during the morning and evening transition periods. Data have

been reported in the literature with measurements made at a limited number of fixed locations.[3] It was hoped that airborne LIDAR data would enable experimenters to extrapolate results from fixed sampling locations with high temporal resolution to obtain modeling information covering the entire St. Louis metropolitan area. The second objective was to compare airborne LIDAR results with radiosonde measurements and other in situ monitoring methods.

A system chart is shown in Figure 1. Basic design criteria included a variety of constraints imposed by aircraft power and safety considerations.

The aircraft used was a C-45 (twin-engine Beechcraft) operated by the EPA. The aircraft has an aerial camera port and the telescope/laser assembly was designed specifically to the dimensions of the port, 45 centimeters (cm) by 50 cm. To reduce the weight of the system, the laser power supply was repacked into two aluminum boxes conforming to aircraft safety requirements. Weight reduction on the power supply alone amounted to about 180 kilograms (400 pounds). The telescope was made using aircraft construction techniques and utilized a plastic Fresnel lens as the light collecting element. Data output from the system was through a fast analog to digital converter. Final data output was on strip charts which were subsequently hand digitized and analyzed using a large digital computer at the Las Vegas Laboratory. Table 1 is a summary of the design parameters.

Comparison data were obtained from in situ monitoring instrumentation located in a mobile van and a helicopter. Instrumentation on both the helicopter and the panel van was the same and consisted of a sulfur dioxide monitor, temperature and humidity sensors, and an integrating nephelometer. Meteorological data were also obtained with radiosondes released during each of the test periods at several fixed locations including the Arch. Wind profiles were obtained both at the Arch and at a rural site.

## RESULTS AND DISCUSSION

A total of 10 flight profiles was obtained during three days of operation. A log of the testing periods is shown in Table 2.

Discussion of the results of the LIDAR flights will concentrate on the urban plume studies of February 23, 1974, and the late evening traverses conducted on February 25, 1974. Extensive meteorological data were obtained during these periods by helicopter, by a mobile van and by ground-based observers at two fixed locations.

1. February 23, 1974

Three traverses were made late in the morning of February 23 to define the dimensions of the urban plume.

Clear skies and low wind velocities on the afternoon and evening of February 22 permitted the formation of a surface-based inversion which did not break up until the afternoon of February 23. Mid-morning warm

air advection enhanced the intensity of the inversion layer resulting in a decision to fly a series of traverses over the anticipated urban plume. The winds during the plume study were east-southeast at the ground veering to southeast near the top of the mixed layer. Wind speeds increased slightly from 5-6 meters/second near the surface to 6-7 meters/second at the top of the mixed layer.

Figure 2 shows the flight traverses,wind vectors at the ground and top of the inversion layer, and the location of ground sites where temperature profiles were obtained. The temperature profile taken at site (4) which was located at the Spirit of St. Louis airport is probably the most representative of the character of the mixed layer at the time the LIDAR measurements were taken (Figure 3). Note the well-defined inversion at 900 meters mean sea level (MSL) with a small kink in the profile at 300 meters MSL, probably representing a convective bubble.

Figure 4 is a computer-generated iso-scattering contour plot of LIDAR data taken on the east to west traverse shown in Figure 2. Aerosol scattering is evident throughout the mixed layer and the depth is consistent with the inversion height of 900 meters in Figure 3. Small areas of increased scattering are seen at either end of the plot and represent emission plumes for power generating plants in the area. The high scattering region over St. Louis was caused by the plume of a power plant located near Baldwin, Illinois, some 60 kilometers southeast of St. Louis. The plume was trapped by the 900-meter inversion and with the principal scattering occurring in a region about 100 meters thick. At the opposite end of the traverse, a region of increased scattering is noted corresponding to the plume from the Labadie power plant (see location of Figure 2). LIDAR profile number 33 is shown in Figure 5 which shows the Labadie plume to be some 100 meters thick with increased and uniform scattering throughout the remainder of the mixed layer.

A north to south traverse was flown from Troy, Missouri, to Washington, Missouri (see Figure 2). Figure 6 is the iso-scattering contour plot of data obtained on this traverse. Boundary layer thickness and scattering distribution are similar to the east to west traverse with the Labadie plume appearing as a region of greatly increased scattering. The large area of increased scattering shown to the left of the figure probably represents the urban plume and is consistent with meteorological data and the location of industrial sites to the east of St. Louis.

2. February 25, 1974

South to north and west to east traverses were made over the St. Louis metropolitan area during late evening of February 25. Figure 7 is a map showing the location of the traverses, location of individual laser firings, ground-based sampling locations, and the surface wind vector.

Skies over St. Louis were clear for the entire day and snow remained on the ground from a snowfall which occurred February 24. Outgoing terrestrial radiation aided by the snow cover produced a strong,

shallow, surface-based inversion in spite of the strong winds. At the time of the flights, both the surface inversion and a slight inversion at 900 meters MSL were observed. The elevated inversion probably represents the extent of the maximum mixing depth on that day. A shallow mixed layer was observed over the urban areas capped by an isothermal layer Surface winds coming from the west shifted to the southwest in the evening and diminished in strength.

Figure 8 is an iso-scattering contour map of the south to north traverse. The upper scattering contour represents remnants of the mixed layer from that day which had risen to between 800 meters and 900 meters. The area of increased scattering near the point of intersection of the traverses represents the plume from the Labadie power plant located southwest of the city. Increased scattering is also noted near the surface and probably represents aerosols generated within the urban area.

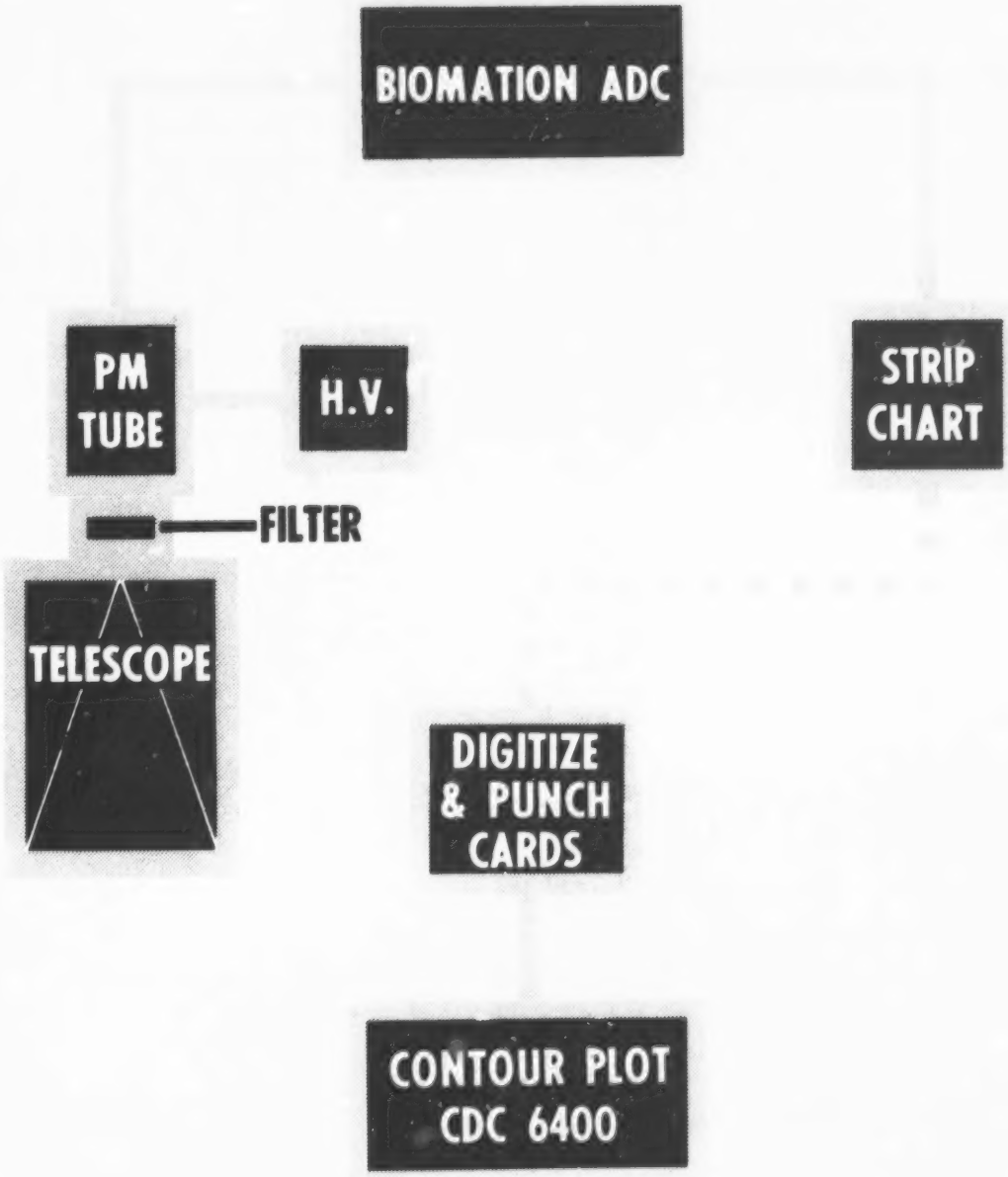


Figure 1. Diagram of airborne LIDAR system

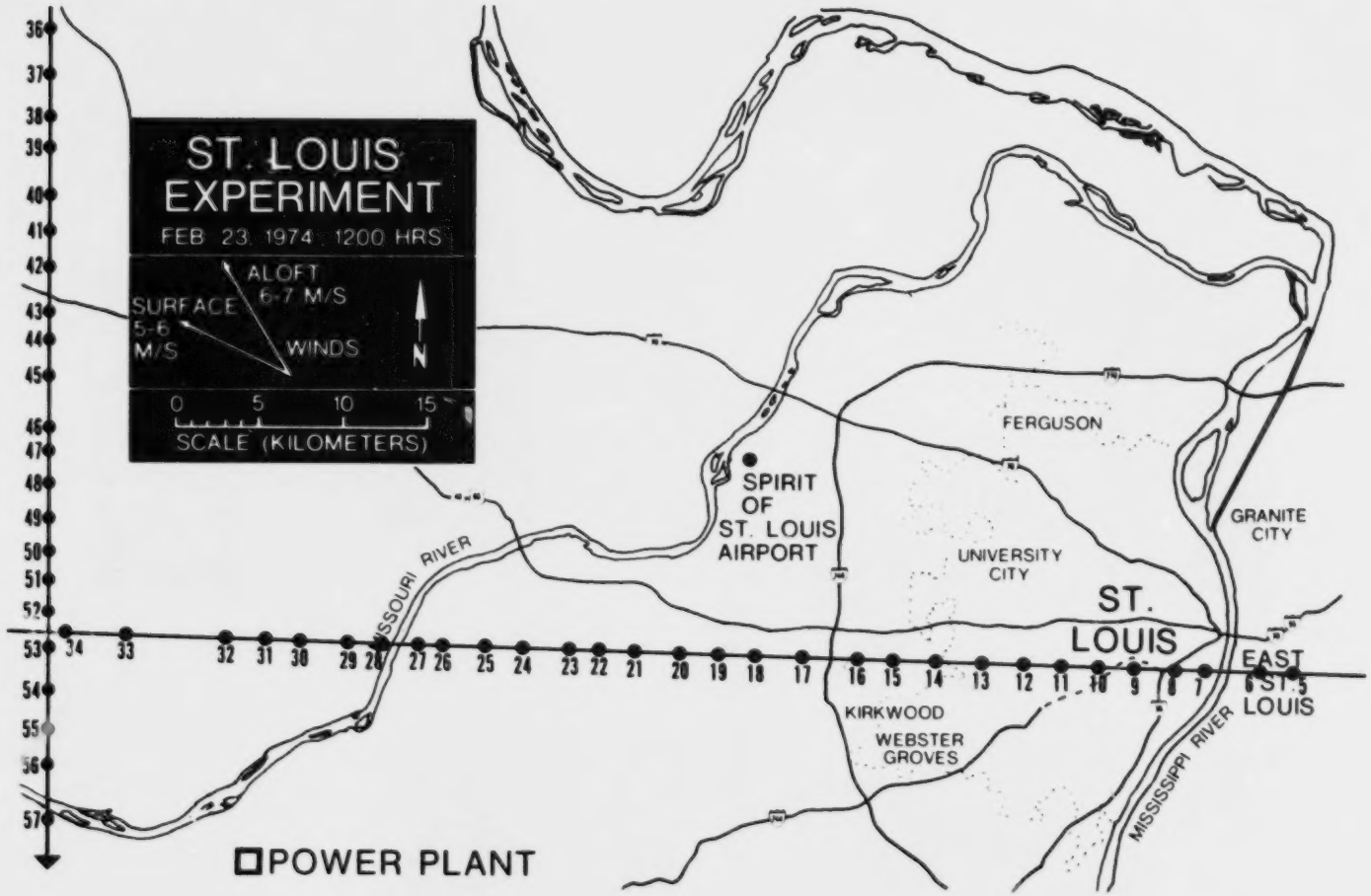


Figure 2. Map of LIDAR traverses, February 23, 1974

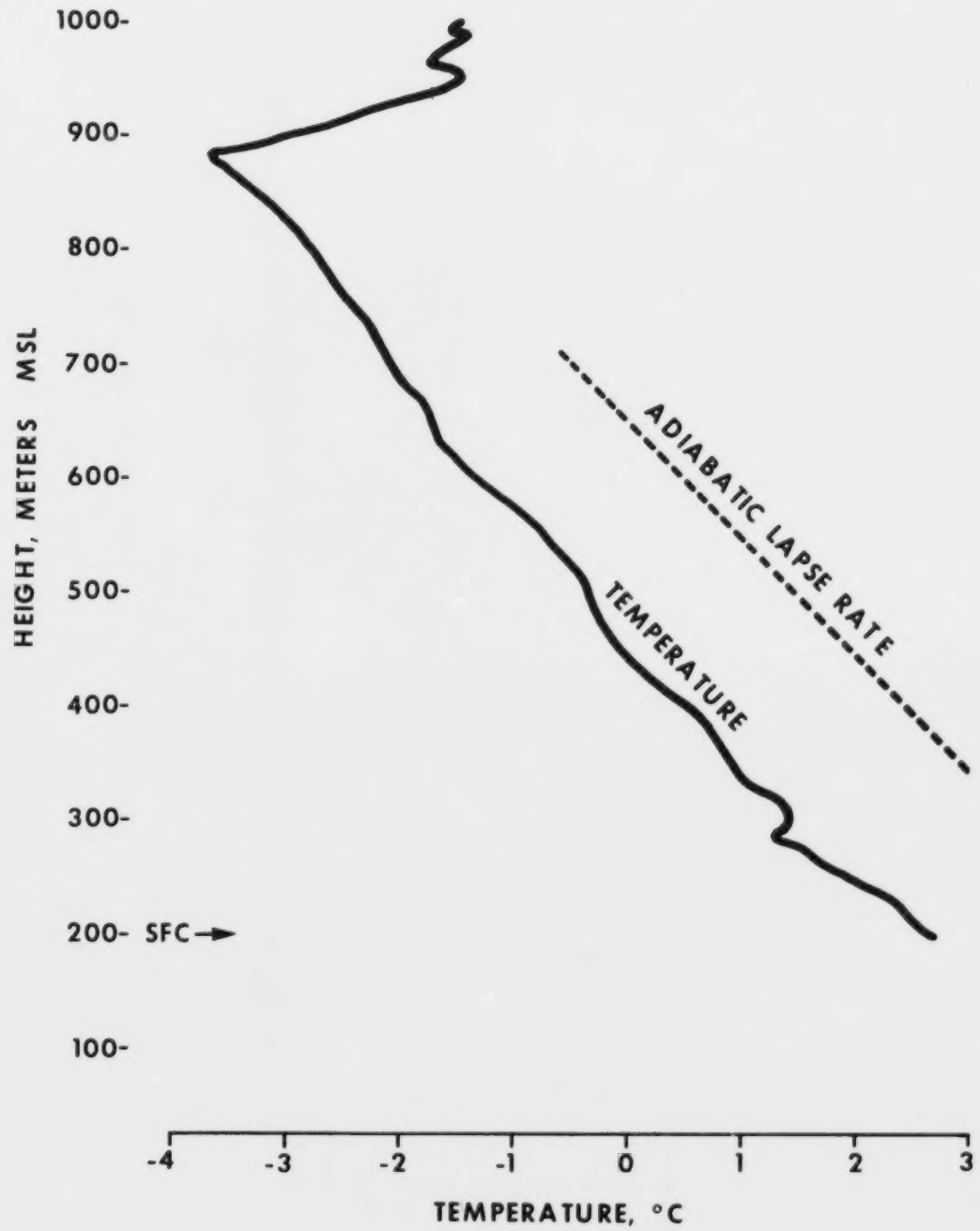


Figure 3. Helicopter profile over Spirit of St. Louis Airport, February 23, 1974

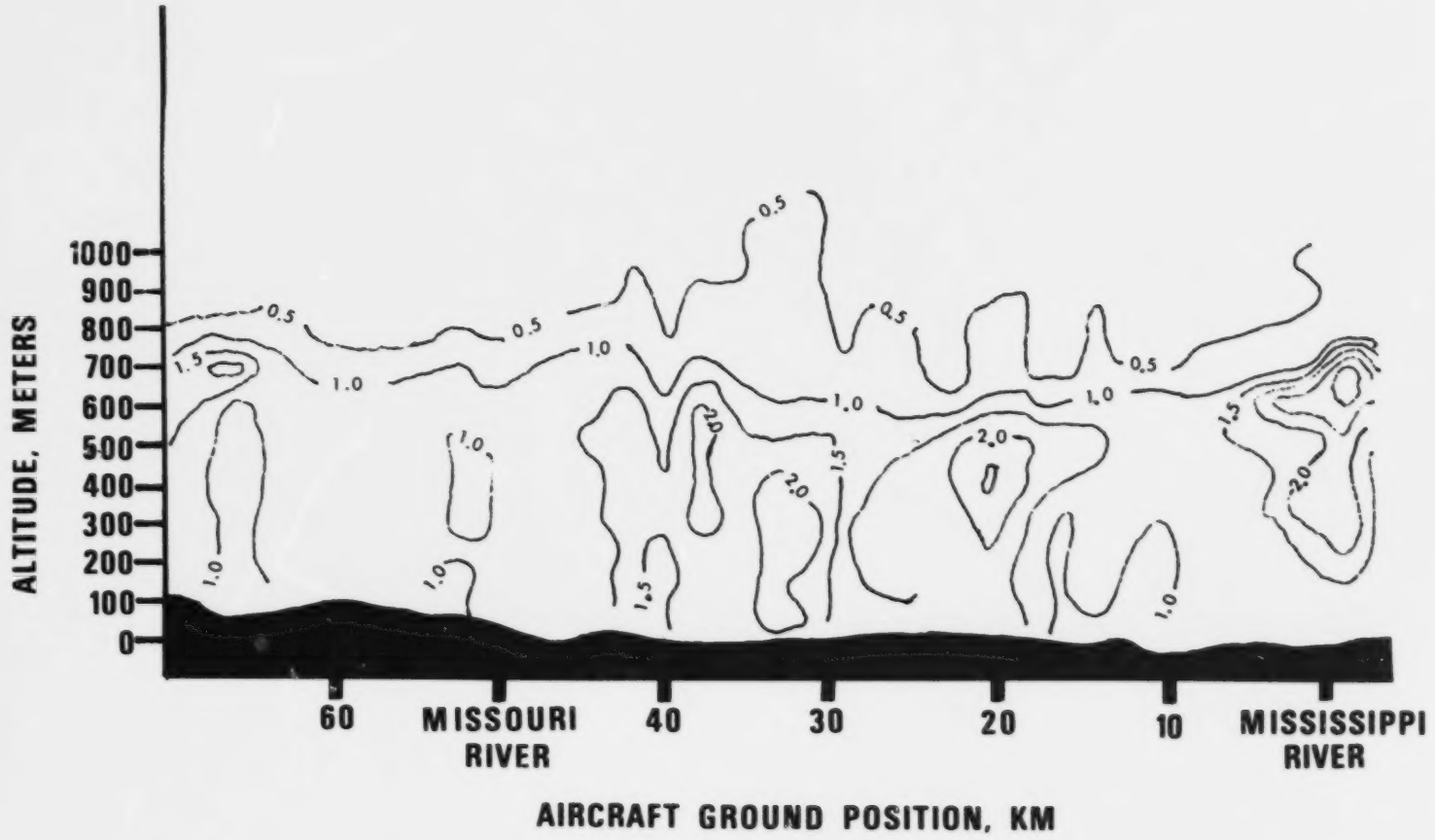


Figure 4. Iso-scattering contour plot, east to west traverse, February 23, 1974

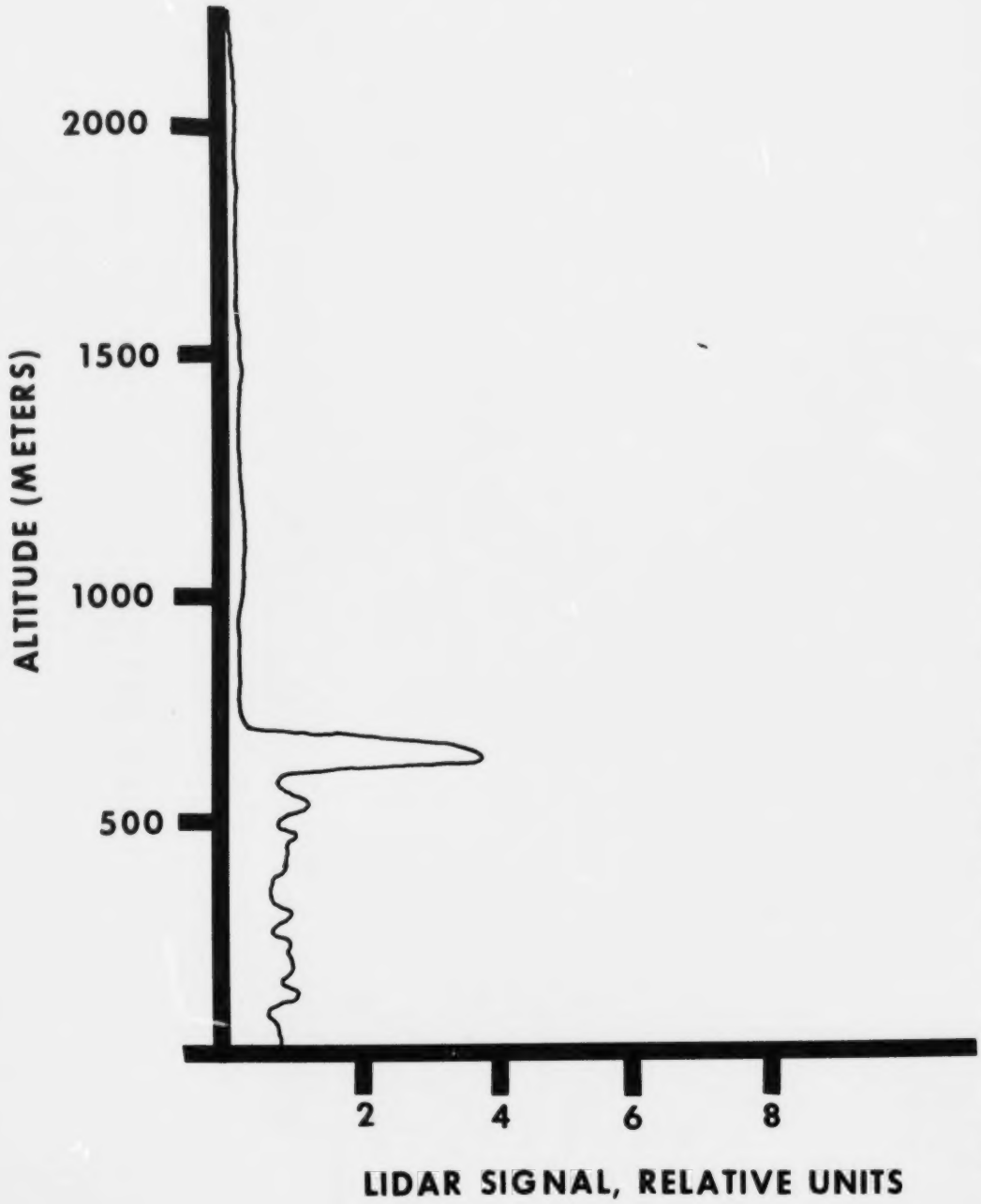


Figure 5. LIDAR profile showing Labadie plume, February 23, 1974

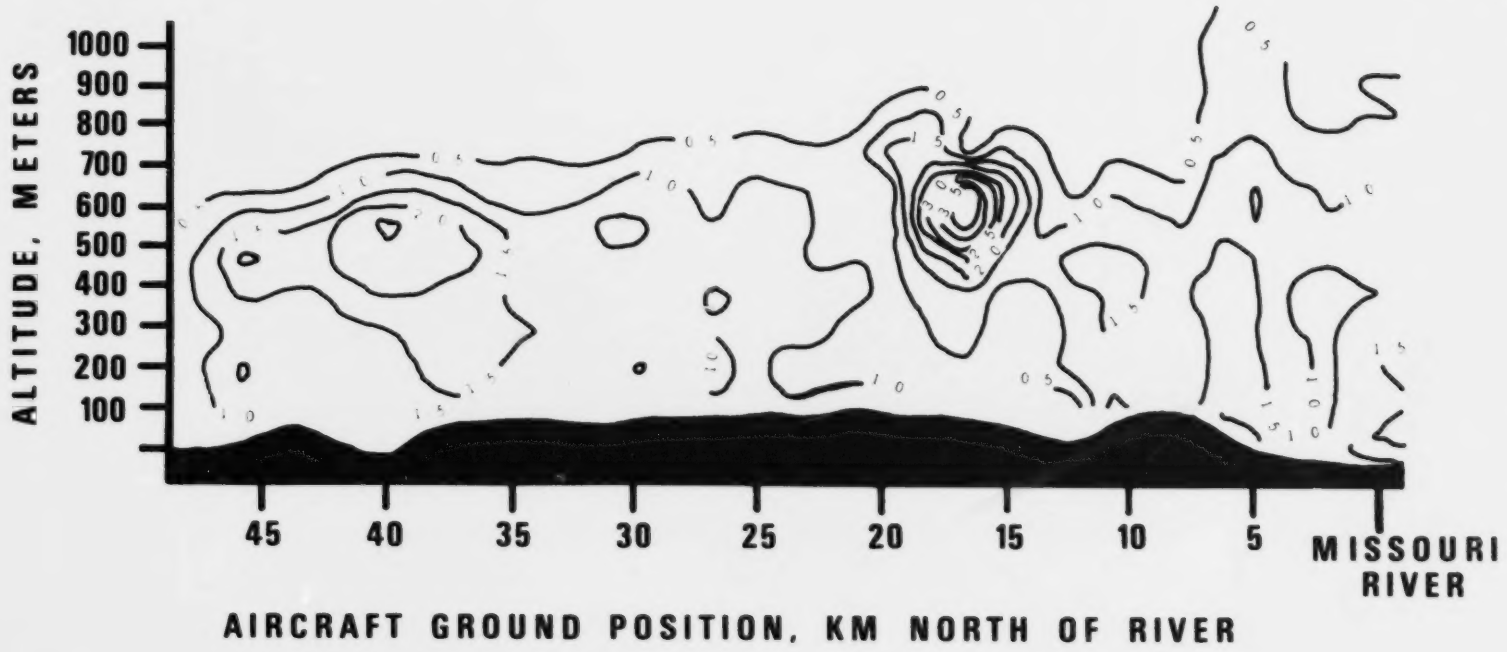


Figure 6. Iso-scattering contour plot, south to north traverse, February 23, 1974

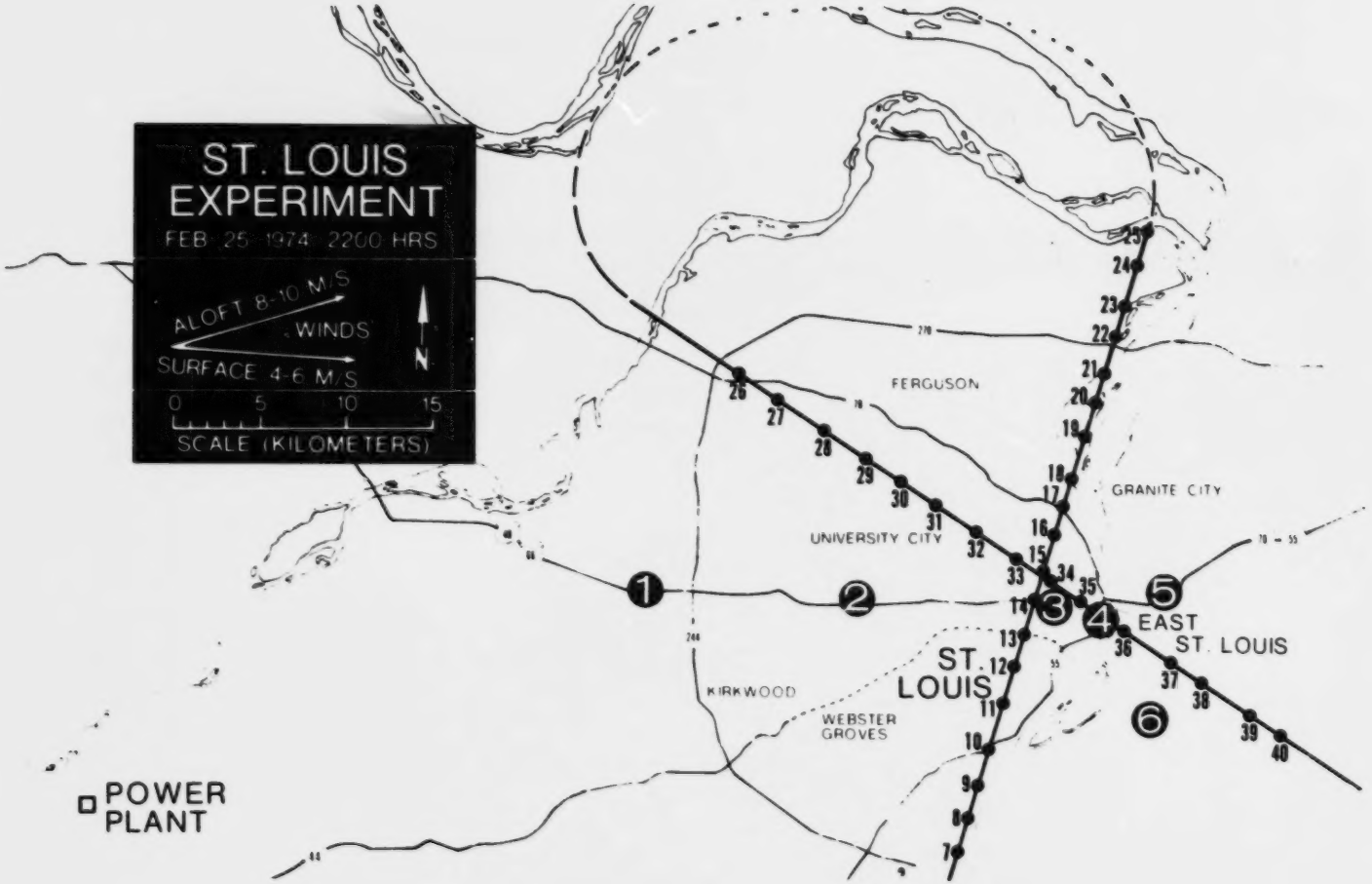


Figure 7. Map of LIDAR traverses, February 25, 1974

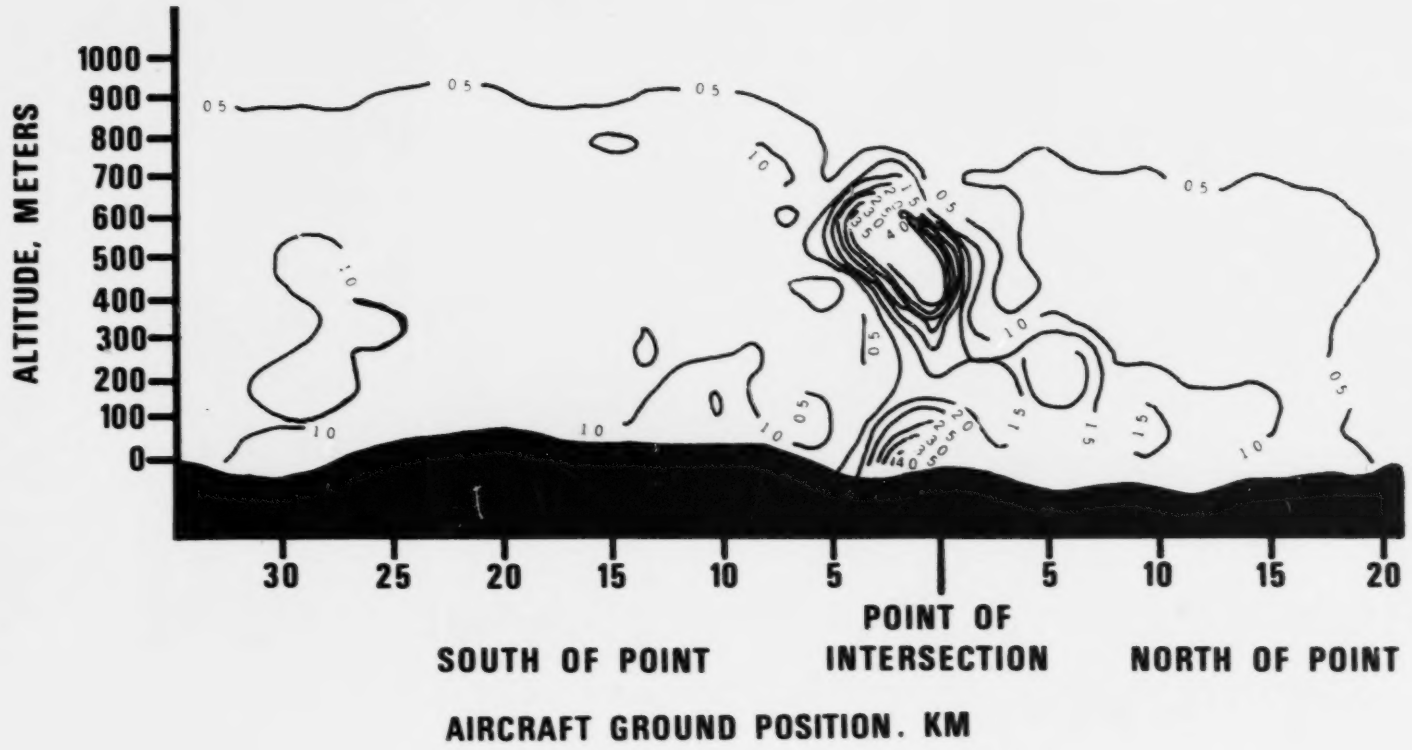


Figure 8. Iso-scattering contour plot, south to north traverse, February 25, 1974

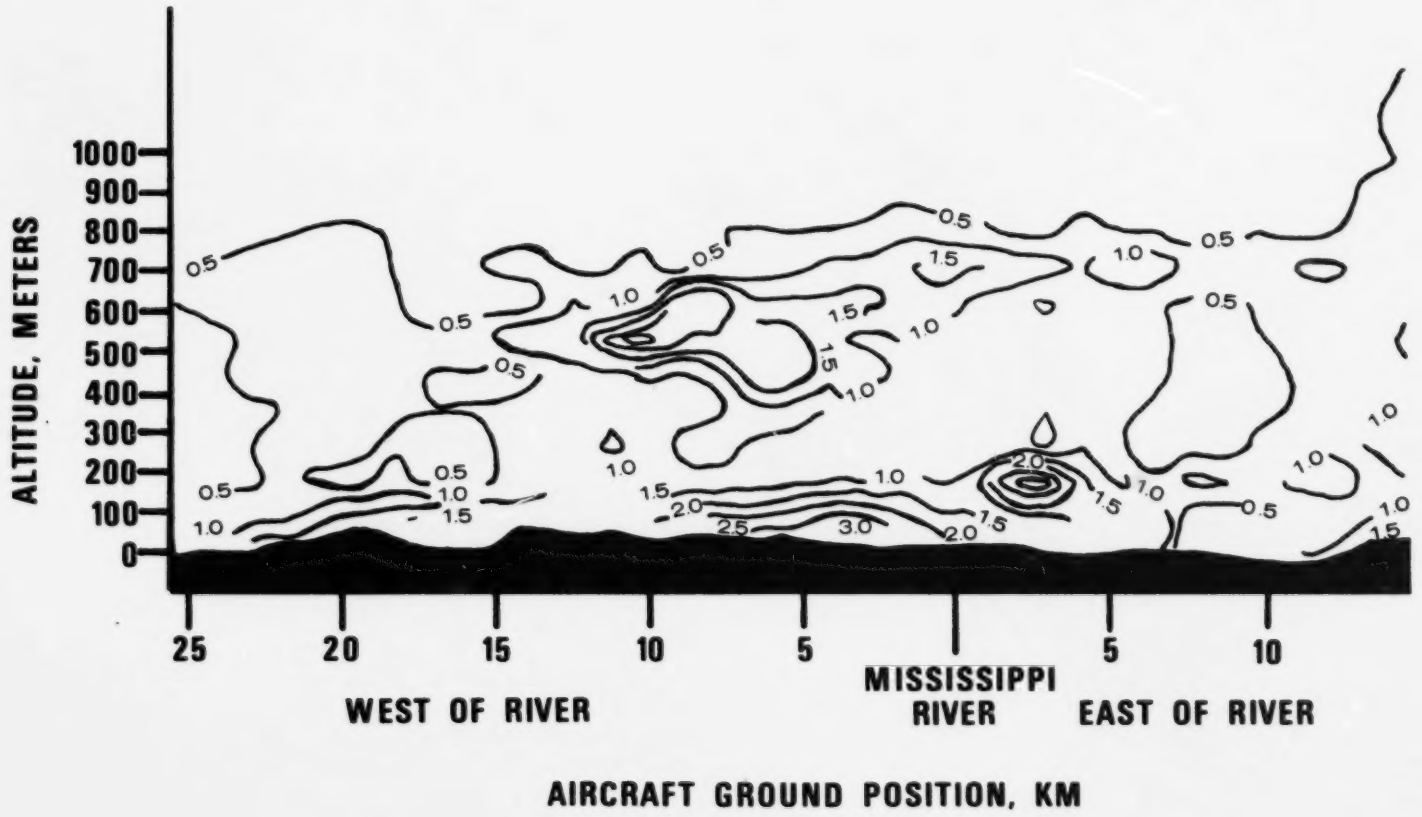


Figure 9. Iso-scattering contour plot, west to east traverse, February 25, 1974

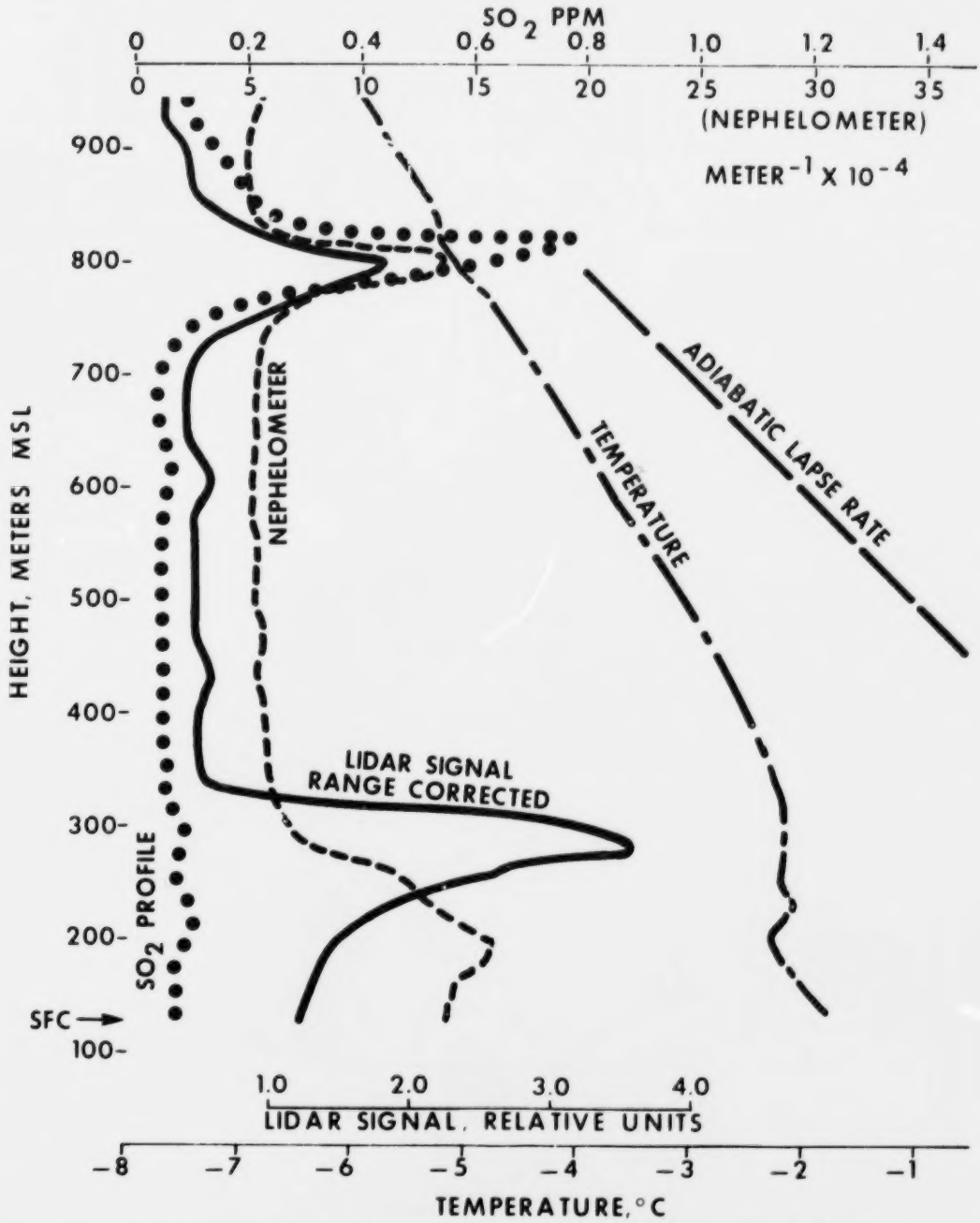


Figure 10. Helicopter profile over Gateway Arch compared with LIDAR signal, February 25, 1974

TABLE 1. SYSTEM PARAMETERS

PHYSICAL:

Laser - Q-Switched Ruby

| | |
|---|---|
| Frequency: | 6943 Å |
| Output Power: | 1 joule |
| Pulse Length: | 20 nsec |
| Firing Rate: | ∿ 0.1 HZ |

Telescope - 38 cm Fresnel Lens, Aircraft Monoque Construction

Detector - RCA C3100A Photomultiplier

Size - 0.5 $m^3$

Weight - ∿350 Kg

Power Requirements - 2KW Peak, 600 Watts Standby

OPERATIONAL:

Altitude - Minimum 3,000 m above ground level for Eye Safety

Horizontal Resolution - ∿750 m

Vertical Resolution - ∿15 m

Sensitivity - 2X Scattering from Clean Air

Signal Rate - 1 pulse every 10 seconds

Output - Strip Chart

Navigation - Visual by Co-Pilot through Window in Cockpit Floor

TABLE 2. TESTING PERIODS

| Date | Time/ Start | Location | # of Laser Firings | Notes |
|---|---|---|---|---|
| 2/23/74 | 06:16 | S-N Over St. Louis | 14 | |
| | 06:41 | W-E Over St. Louis | 14 | |
| | 11:34 | E-W Over St. Louis | 34 | Attempt to |
| | 12:00 | N-S Troy, MO to Washington, MO | 26 | find dimen- sions of |
| | 12:37 | S-N Pacifich, MO to O'Fallen, MO | 15 | the urban plume |
| | 12:48 | W-E Over St. Louis | 18 | " |
| 2/25/74 | 21:58 | S-N Over St. Louis | 25 | Night flight in |
| | 22:21 | W-E Over St. Louis | 15 | very clear air |
| 2/26/74 | 09:19 | S-N Over St. Louis | 20 | Snow on ground |
| | 09:52 | W-E Over St. Louis | 23 | |

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